Pedobiologia **37**, 270–279 (1993)
Gustav Fischer Verlag Jena

Investigations on lead in the soil invertebrates of a forest ecosystem

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Summary. The distribution of Pb in soil-dwelling invertebrates of a spruce stand in South Germany, which is contaminated by Pb-emissions from car exhausts was studied. In the most abundant species of litter decomposers (Lumbricidae, Enchytraeidae, Oribatida, Diplopoda, Diptera) and their predators (Carabidae, Staphylinidae, Araneae) the concentrations of Pb were determined by graphite furnace atomic absorption spectrometry.

Annelids (*Lumbricus rubellus, Cognettia sphagnetorum*) showed essentially higher concentrations of Pb than arthropods. Among the arthropods highest concentrations of Pb were found in oribatid mites and millipedes, which are characterized by having enhanced calcium requirements. In addition, concentrations above the average of arthropods were found in detritophagous collembolans (*Lepidocyrtus lignorum, Tomocerus minor, Entomobrya nivalis*), sciarids and cecidomyiids, which feed – at least partly – on fungal hyphae, and spiders (*Diplocephalus latifrons, Robertus lividus, R. neglectus*), feeding predominantly on these Collembola and Diptera.

Detritophagous invertebrates had on average higher Pb-levels than zoophagous groups. The differences in Pb-content between litter decomposers and their predators were significant (Mann-Whitney-U-test: $P \leqq 0.01$), indicating no tendency for Pb to be concentrated with increasing trophic level. There was no evidence for biomagnification of Pb in any of the predator-prey relationships examined.

Key words: Lead, soil invertebrates, Lumbricidae, Enchytraeidae, Araneae, Oribatida, Diplopoda, Diptera, Coleoptera, biomagnification

Introduction

Since the beginning of industrialization, Pb has contributed substantially to environmental pollution in the northern hemisphere and represents an ubiquitous hazard to the biosphere. In addition to emissions caused by industrial processes, considerable amounts of Pb are released into the environment by the combustion of fossil fuels, especially of gasoline to which organic lead is added as an anti-knock agent. Thus, in the densely settled northern hemisphere most terrestrial and aquatic ecosystems are affected by the deposition of airborne lead compounds.

In woodland ecosystems, the greatest accumulation of heavy metals occurs in the litter layer (e.g., Martin et al. 1982). Therefore, organisms inhabiting the humus horizons are often exposed to high levels of Pb (Bengtsson & Rundgren 1984; Hopkin 1989). The organic soil horizons are colonized by a species-rich animal community. In addition to the Protozoa, invertebrate animals are among the most abundant soildwelling organisms (Funke 1986). Different trophic groups among nematodes, gastropods, annelids and arthropods of forest soils are involved in essential ecosystem processes, such as the decomposition of litter and the transfer of elements in food chains.

Most data on Pb in soil animals of forest ecosystems are restricted to lumbricids, isopods or snails (Weigmann 1991; Hopkin 1989). Only a few investigations on heavy metals have included numerous species of the soil invertebrate community (e.g., Bengtsson & Rundgren 1984; Van Straalen & Van Wamsen 1986). The present study reports on the distribution of Pb in soil invertebrates (Annelida, Arthropoda) in a spruce stand in South Germany. In addition to considering the influence of taxonomic and trophic level on Pb concentrations, the tendency of Pb to be concentrated with increasing trophic level is examined.

Materials and Methods

Study site

The investigations on Pb in soil invertebrates were conducted in an 80-year-old-monoculture of Norway spruce (*Picea abies* L. Karst.). The study site (U1) is situated 3 km northwest of Ulm ("Swabian Alb", South Germany). The area has a uniform topography (elevation 613 m). The coniferous trees grow on gley-like soils (sekundärer Pseudogley), developed from sedimentary rocks (white jurassic limestone/Weißjura). The humus form is of the mor-type with well distinguished layers of litter (O_l) fermentation (O_f) and humification (O_h) and pH_{KCl}-values between 3.0 and 4.3.
The U1-site is influenced by Pb-emissions. This assumption is confirmed by increased levels of Pb in the humus layers of U1 ($O_{l/f}$: 48 ppm, O_h: 116.4 ppm) compared with background levels in uncontaminated ecosystems (Roth 1991). The Pb-contamination of U1 is largely attributable to exhaust gases of automobiles from a highway in the vicinity of the spruce stand and in the direction of the prevailing winds.

Invertebrate animals

In acidic coniferous forest soils, the species spectrum and dominance structure of the invertebrate community is dominated by nematodes, annelids and – within the arthropods – by spiders, mites and insects. With the exception of nematodes, the elemental analyses were carried out on the most abundant species of permanent or temporary soil-dwelling annelids and arthropods (Table 1). Investigations on Oribatida were related to *Adoristes poppei* (Oudemans), *Chamobates schuetzi* (Oudemans), *Hermannia gibba* Koch, *Archipteria coleoptrata* Linné, *Oppiella nova* (Oudemans), *Dissorhina ornata* (Oudemans), Medioppia *subpectinata* (Oudemans), *Oribatella calcarata* (Koch), *Phtiracarus piger* (Scopoli), *Platynothrus peltifer* (Koch), *Suctobelbella sarekensis* (Forsslund) and *Tectocepheus velatus* (Michael), and investigations on Sciaridae to *Corynoptera trispina* Tuomikoski, *Ctenosciara hyalipennis* (Meigen), *Lycoriella fucorum* (Frey) and *Epidapus atomarius* (Degeer)

Sampling of soil invertebrates and needle litter

Ground photoeclectors and pitfall traps were employed during the vegetation period in 1986 and 1987 for representative sampling of emerging insects with soil-living stages of development (Diptera) or for surface-dwelling arthropods (Araneae, Oribatida, Julidae, Collembola, Carabidae, Staphylinidae). Euedaphic animals, such as enchytraeids or oribatid mites were quantified by extracting soil-core samples. Lumbricids were sampled with the Octet-Method. Aliquots of needle litter from the litter- and fermentation layers of the humus horizons were sampled at monthly intervals (April-October) in 1986 and 1987. Detailed information on sampling is given by Roth (1991).

Sample-preparation

Invertebrates were kept for 2–4 days in plastic petri dishes containing moist filter paper to void their gut contents. Animals were killed by freezing and cleaned of surface contamination in an ultrasonic bath with distilled water. After lyophilization and homogenization, the samples were ashed in teflon autoclaves (Bergmann, Tübingen, Germany) at 160 °C for 4 h, using concentrated nitric acid (HNO_3 65% v/v) for the digestion of the invertebrates and an combination of fluoric and nitric acid (HF 40% v/v: HNO_3 65% v/v = 1:9) for the digestion of needle litter. All reagents used for the digestion

of the samples were of highest purity (Suprapure, Merck, Darmstadt, Germany). Calibration standard solutions were prepared from Titrisol concentrates (Merck, Darmstadt, Germany).
Because of the low individual weights of invertebrates, individuals of *C. sphagnetorum*, *Diplocephalus latifrons*, *Robertus* sp., *Entomobrya nivalis*, *Lepidocyrtus lignorum*, *Orchesella flavescens*, *Tomocerus minor*, *Tachinus laticollis*, *T. rufipes*, *Tachyporus obtusus*, Oribatida, Sciaridae and Cecidomyiidae were pooled for Pb analysis.

Analytical methods

Concentrations of Pb in invertebrates and needle litter were determined by graphite furnace atomic absorption spectroscopy, using a Perkin-Elmer deuterium-background corrected AAS 1100 in combination with a HGA 400 and an AS 40 autosampler.
The accuracy of the procedure was confirmed by measuring biological standard reference materials of the "National Institute of Standards and Technology" (Washington D.C.). Recovery rates of Pb ranged between 97 and 106% for "Bovine liver" and "Pine needles", respectively.

Results

Lead concentrations in annelids and arthropods

In the soil-dwelling annelids and arthropods of the U1-site, the concentrations of Pb ranged between 0.3 and 76.0 ppm (Table 1). The highest concentrations of Pb were found in enchytraeids (*Cognettia sphagnetorum*), and the lowest in the spider *Coelotes terrestris* and in staphylinid beetles (*Tachinus laticollis*, *Philonthus fuscipennis*). Placing the invertebrates into categories according to their taxonomic level, the concentration of Pb followed the order Annelida > Arthropoda (Table 2). The differences in the Pb content of annelids and arthropods were statistically significant (Mann-Withney-U-test: $P \leqq 0.01$).
Within the arthropods, highest values of Pb were found in oribatid mites, collembolans, diplopods, cecidomyiids and sciarids. Staphylinids, carabids, tipulids and some spiders were characterized by lowest levels of Pb (Table 1 and 2).

Table 1. Lead concentrations (ppm) or forest soil invertebrates

Species	Pb concentration (mean values ± 95% confidence interval)	number of animals analysed
Lumbricidae		
Lumbricus rubellus Hoffmeister	57.6 ± 21.4	(17)
Enchytraeidae		
Cognettia sphagnetorum Vejdovsky	76.0 ± 63.6	(1562)
Araneae		
Coelotes terrestris (Wider)	0.3 ± 0.3	(78)
Diplocephalus latifrons (O.P.-Cambridge)	4.7 ± 1.4	(257)
Robertus lividus (Blackwell) and *R. neglectus* (O.P.-Cambridge)	4.4	(24)
Oribatida	38.6 ± 1.8	(29000)
Diplopoda		
Julus scandinavius Latzel	5.5 ± 1.2	(31)
Collembola		
Entomobrya nivalis (Linné)	9.1 ± 2.3	(3705)
Lepidocyrtus lignorum Fabricius	5.2 ± 3.6	(2022)
Orchesella flavescens (Bourlet)	1.3	(272)
Tomocerus minor (Lubbock)	7.5 ± 2.6	(4225)

Table 1. (continued)

Species	Pb concentration (mean values ± 95% confidence interval)	number of animals analysed
Carabidae		
Abax parallelepipedus (Piller et Mitterpacher)	1.9 ± 0.7	(30)
Abax parallelus (Duftschmid)	0.9 ± 0.2	(10)
Carabus auronitens Fabricius	0.4 ± 0.2	(10)
Carabus granulatus Linné	0.4 ± 0.3	(12)
Carabus hortensis Linné	1.1 ± 0.3	(12)
Loricera pilicornis (Fabricius)	1.9 ± 2.3	(15)
Notiophilus biguttatus (Fabricius)	0.8	(33)
Pterostichus metallicus (Fabricius)	0.7 ± 0.3	(36)
Pterostichus oblongopunctatus (Fabricius)	1.4 ± 0.4	(48)
Staphylinidae		
Ontholestes tesselatus (Geoffr. Fourcr.)	1.9 ± 2.1	(16)
Othius punctulatus (Gze)	1.1	(30)
Philonthus fuscipennis (Mannh.)	0.3 ± 0.1	(20)
Philonthus xanthopus Er.	1.0 ± 0.5	(22)
Tachinus laticollis Grav.	0.3	(51)
Tachinus rufipes (Deg.)	0.5	(32)
Tachyporus obtusus (L.)	8.5	(55)
Sciaridae	3.1 ± 0.2	(22500)
Cecidomyiidae	4.7 ± 2.1	(30000)
Tipulidae		
Tipula scripta Meig.	0.5 ± 0.2	(219)
Tipula sp. Typ A	0.5 ± 0.4	(26)
Tipula sp. Typ B	0.4 ± 0.1	(20)

Table 2. Lead concentrations (ppm) in taxonomic groups of forest soil invertebrates

Taxonomic Group	Mean value ± 95% confidence interval
Annelida	66.8 ± 6.5
Arthropoda	9.9 ± 9.0
Acari (Oribatida)	38.6 ± 1.8
Diplopoda	5.5 ± 1.2
Araneae	3.2 ± 2.3
Insecta	3.3 ± 1.2
Collembola	5.8 ± 2.9
Cecidomyiidae	4.7 ± 2.1
Sciaridae	3.1 ± 0.2
Staphylinidae	1.9 ± 2.0
Carabidae	1.1 ± 0.4
Tipulidae	0.5 ± 0.1

Table 3. Lead concentrations (ppm) in trophic groups of forest soil invertebrates

Trophic level	Mean values ±95% confidence interval
Litter decomposers	19.0 ± 13.3
Predators	1.7 ± 0.9

Placing the invertebrates according to their feeding strategy, litter decomposers contained significantly ($P \leqq 0.01$, Mann-Whitney-U-test) higher levels of Pb than predatory arthropods (Table 3).

Lead concentrations in the humus layer of the spruce stand

To calculate the concentration factors of Pb in litter decomposing invertebrates, it was necessary to determine the concentrations of Pb in the humus layer ($O_{l/f}$) of the spruce stand. The concentration in the litter and fermentation layer of the soil was 48.0 ± 12.6 ppm (mean value ± confidence interval, $P \leqq 0.05$).

Concentration factors of lead in soil invertebrates

Investigations on the biomagnification of Pb were carried out on litter decomposers and their predators. To indicate the accumulation potential of Pb in food chains of soil invertebrates, the concentration factors (CF) were calculated as follows:

$$CF = \frac{\text{Pb concentrations (ppm) in invertebrate species}}{\text{Pb concentrations (ppm) in their diet}}$$

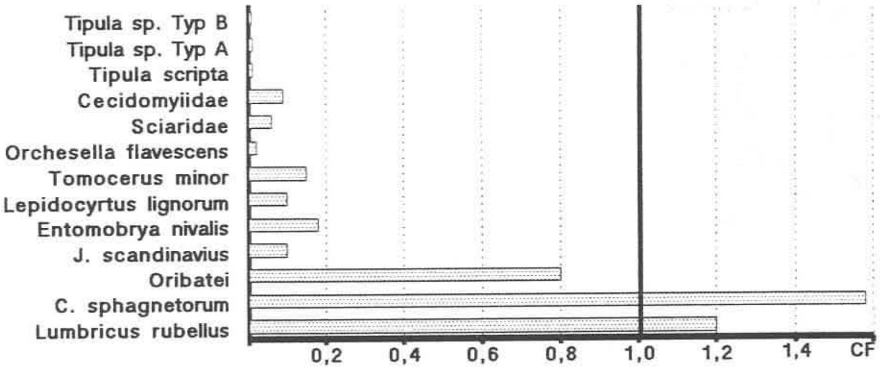

Fig. 1. Concentration factors (CF) of Pb in litter decomposing invertebrates from the U1-site

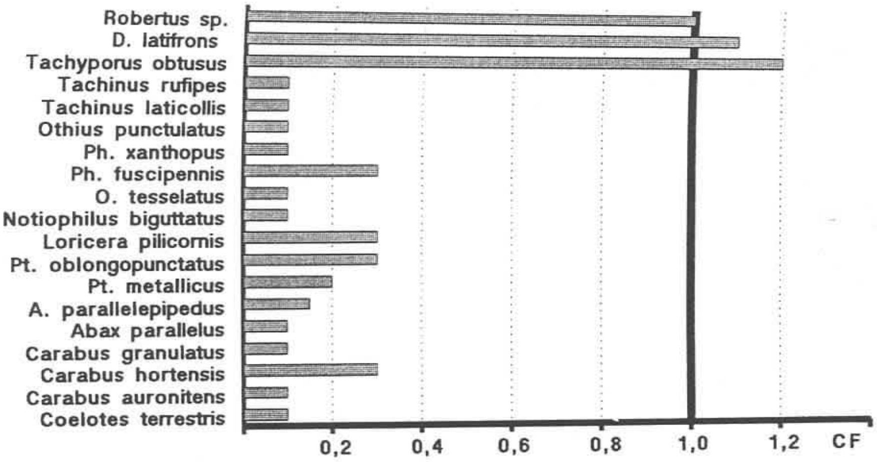

Fig. 2. Concentration factors (CF) of Pb in zoophagous arthropods from the soil surface

Generally, in the soil-dwelling invertebrates of the spruce stand Pb showed no tendency to be concentrated with increasing trophic level. In litter decomposing invertebrates the concentration factors ranged between 0.01 and 1.58 (Fig. 1), and in predatory arthropods between 0.1 and 1.2 (Fig. 2). Slightly enhanced Pb levels compared to their diet, with concentration factors about one ($1.0 \leqq CF \leqq 1.58$), were only manifested for *C. sphagnetorum*, *L. rubellus*, *D. latifrons* and *T. obtusus*. In most representatives of litter decomposers and zoophagous invertebrates concentration factors were less than unity. Within detritophagous invertebrates lower Pb levels than the $O_{l/f}$-layer of the humus horizon were recorded in millipedes, collembolans and dipterans (Fig. 1). Lower Pb levels compared to their prey objects were recorded in all predatory arthropods, especially carabids, and, with the exception of *T. obtusus*, staphylinids (Fig. 2).

Discussion

Concentrations of lead in soil invertebrates of the spruce stand

Due to the capacity of organic soil fractions to act as sinks for heavy metals (e.g., Martin et a. 1982; Mayer 1981), edaphic organisms are mostly exposed to higher levels of Pb than aboveground animals (Roth 1992). This is especially true of forest ecosystems, where metal input is enhanced because of the filter function of the forest canopy (Lindberg 1989). Since the Pb content of many invertebrates is, within certain limits, a function of lead pollution in the environment (e.g., Gish & Christensen 1973; Ma et al. 1983; Martin et al. 1976; Morgan & Morgan 1990; Roberts & Johnson 1978) field populations of soil invertebrates from areas close to sources of metal pollution often show remarkably high levels of Pb. Thus, in woodlice, snails and springtails from contaminated environments Hopkin (1989, 1990) and Joosse & Buker (1979) reported Pb concentrations of 508 ppm, 120 ppm, and 86 ppm, respectively. Specimens of the spider *Trochosa terricola*, which were collected in the vicinity of a brass mill, contained 62 ppm of Pb (Bengtsson & Rundgren 1984). Earthworms, especially from highly contaminated sites, can accumulate up to several thousand µg Pb/g dry weight (Ireland 1983).

In the soil-dwelling annelids and arthropods of the U1-site the concentrations of Pb were far below the Pb concentrations of invertebrates from environments which are highly contaminated by industrial sources. Nevertheless, the influence of Pb emissions on the U1-site are obvious. As shown especially for lumbricids, Pb concentrations in soil invertebrates at the U1-site exceeded the levels in animals collected from uncontaminated areas (Roberts & Johnson 1978) and correspond with the Pb concentrations of invertebrates inhabiting sites in the vicinity of highways. Thus, similar concentrations of Pb occur in invertebrates in different terrestrial ecosystems which are influenced e.g., by exhaust gases of automobiles (Gish & Christensen 1973; Weigmann 1991; Williamson & Evans 1972).

Influence of the taxonomic level on lead concentrations in soil invertebrates

At the U1-site annelids showed essentially higher concentrations of Pb than arthropods. This hierarchy indicates the influence of group or species-specific properties on Pb content of soil-dwelling invertebrates.

In most terrestrial invertebrates, the epithelium of the gut is almost entirely responsible for the exchange of metals with the environment (Hopkin 1989). Exceptions are probably soft-bodied invertebrates living in close contact with the soil substratum, such as enchytraeids and lumbricids. Besides the ingestion of metals via the alimentary canal, surface absorption of Pb may be responsible for the higher concentrations of Pb in annelids as compared to arthropods. For earthworms, the absorption of Pb through the body wall has been demonstrated by Wielgus-Serafinska & Kawka (1976). According to Fleming &

Richards (1982) a high proportion of Pb is associated by physiochemical forces with extracellular compounds of the cuticular mucoprotein layer of lumbricids.

Highest concentrations of Pb have always been found in taxonomic groups which are characterized by storage detoxification strategies, such as isopods, gastropods and lumbricids (Hopkin 1989; Martin & Coughtrey 1982; Williamson & Evans 1972). The hepatopancreas is the most important storage organ for Pb and other heavy metals such as Cd and Zn, especially in isopods and gastropods (Hopkin 1989). In lumbricids storage excretion of heavy metals has been demonstrated for the chloragocytes (Morgan & Morgan 1989). In contrast to some insects and other arthropods (except isopods), which discharge toxic metals as least partly by moulting (Emets & Zhulidov 1981; Van Straalen & Van Meerendonk 1987), the storage detoxification strategy may be one explanation for the remarkably high concentrations of Pb in earthworms.

Within the arthropods highest concentrations of Pb were found in groups which are characterized by enhanced Ca requirements due to Ca-enriched-exoskeleton (Roth 1992). Since Pb is thought to follow biochemical pathways similar to calcium, the high concentrations of Pb in oribatid mites and *J. scandinavius* (Diplopoda) at the U1-site may be due to an increased uptake of Ca. Higher Pb levels in animals with calcareous exoskeletons than in other invertebrates have been noted by Williamson & Evans (1972). According to Beeby (1978) both cations increased markedly in the woodlouse *Porcellio scaber* with increasing dosage and a clear correlation existed between the rates of uptake of Pb and Ca. In addition, interactions between Ca and Pb are obvious in lumbricids and vertebrates (Gullvag et al. 1975; Morgan & Morgan 1988).

Nutritional influences on lead concentrations of soil invertebrates

With the exception of zoophagous Araneae, Carabidae and Staphylinidae, the soil-dwelling arthropods (Oribatida, Diplopoda, Collembola, Diptera) and annelids (Enchytraeidae, Lumbricidae) of the U1-site are involved in the decomposition of needle litter (Roth 1991). *L. rubellus*, *J. scandinavius*, Tipulidae and Sciaridae are generally regarded as primary decomposers (references cited by Roth 1991). Enchytraeids, oribatids and cecidomyiids mostly prefer plant material in a more advanced state of decomposition (references cited by Roth 1991). In addition, the diets of Enchytraeidae, Oribatida, Collembola, Cecidomyiidae and Sciaridae consist at least partly of fungal mycelia colonizing the humus layers of forests.

Placing the species in categories according to their trophic level, detritophagous invertebrates showed on average higher Pb-levels than predators. Besides species- or group-specific properties (e.g., pathways of metal uptake, detoxification strategies) this discrepancy may be due to differences in the Pb content of the feeding substrate of detritophagous and zoophagous invertebrates. At the U1-site, the Pb concentration of the humus layer (the diet of detritophagous arthropods and annelids) exceeds Pb levels of most potential prey objects of zoophagous arthropods.

In addition, this contrast is, to a certain degree, probably also attributed to differences in food turnover of primary and secondary consumers. Plant material, especially litter, is less rich in energy than animal tissues. To obtain sufficient energy for the maintenance of physiological functions, litter decomposers need to consume more food, with corresponding higher amounts of Pb, than predators.

One of the most important factor, influencing Pb of invertebrates is the availability of Pb in the feeding substrate. Compared to litter decomposers, the lower levels of Pb in zoophagous arthropods may be due to a reduced availability of Pb in prey objects. In most invertebrates potentially toxic heavy metals are stored – in addition to the exoskeleton – in intracellular granula, which consist either predominantly of concentric layers of amorphous calcium and magnesium ortho- and pyrophosphates or are characterized by a high content of sulphur (Hopkin 1989). These granula are found in the chloragogenous tissue of earthworms, in the hepatopancreas of isopods, snails and spiders, and in intestinal cells of insects (Hopkin 1989). All Araneae and most Carabidae and Staphylinidae digest their prey pre-orally (Riechert & Harp 1987; Forsythe 1982). The mandibles or chelicerae are used to penetrate the prey, then, digestive fluids are injected. Dense setae in the mouthregion act as filters when liquified soft internal tissue are subsequently absorbed. Sclerotized or encrustated body walls are mostly rejected as diet. Metals, associated with the cuticle are not transformed by digestive enzymes into "soluble compounds" and, thus, are not available for intestinal absorption by predators. The same could be true for the Pb-containing and mostly insoluble intracellular granula of prey objects.

As already shown for nutrient elements (Roth 1992), litter decomposers that feed partly on fungal mycelia of the humus horizons (Enchytraeidae, Oribatida, Cecidomyiidae, Sciaridae) contained higher amounts of Pb than purely saprophagous groups, such as Tipulidae (Table 2). The influence of (myceto)saprophagous feeding strategy on body concentrations of Pb was especially obvious in soil-dwelling Collembola. *Orchesella flavescens*, a species feeding in the litter layer predominantly on macrophytic wastes, contained less Pb than the mycetosaprophagous species *Lepidocyrtus lignorum* and *Tomocerus minor* (Roth 1992).

Biomagnification of lead in soil invertebrate food chains

From the ecotoxicological point of view, chemical compounds tending to accumulate in food chains are considered as critical, even if they are regarded as non hazardous on the basis of toxicity tests (Borgmann et al. 1990). For Pb the toxic potential to terrestrial and aquatic organisms has already been well documented (Hopkin 1989; Wren & Stephenson 1991). Contrary to the uptake of most essential metals, which is regulated in many invertebrates to a large extent as a function of physiological requirements (Hopkin 1989; Roth-Holzapfel & Funke 1990; Roth 1992), Pb levels of annelids and arthropods are to a certain degree dependent on substrate concentrations. Thus, especially in contaminated environments, toxic levels may be reached easily, if biomagnification takes place. Therefore, investigations on Pb transport in food chains are of special importance.

In previous investigations the bioconcentration of Pb in aquatic food chains was shown to be low (Prahalad & Seenayya 1989; Wren & Stephenson 1991). Concentration factors calculated from total Pb-content of animals and their feeding substrate were mostly less than unity.

In terrestrial ecosystems investigations on the biomagnification of Pb have yielded contradictory results. Price et al. (1974) concluded that biomagnification of Pb occurred in different trophic groups of arthropods from road side ecosystems, although the observations were restricted to insects categorized only according to their feeding type, and distinct food chain relationships were not evident. Willamson (1979) demonstrated that the concentration factors for Pb in *Cepea hortensis* varied from 0.09 to 4.9. Investigations on Pb concentrations in lumbricids, isopods and lepidopteran caterpillars have shown consistently that concentration factors for Pb are less than unity (Andersen 1979; Beyer & Moore 1980; Ireland 1983; Ma et al. 1983; Martin et al. 1976; Van Hook 1974). Only in very acidic soils with enhanced levels of Pb did Pb concentrations in earthworms exceed the substrate values (Ireland 1975).

The low tendency of Pb to be concentrated by litter decomposing invertebrates was manifested for annelids and arthropods of the U1-site. In these invertebrates concentration factors varied around 1.0, or were far less than unity.

In addition, Pb was not concentrated with increasing trophic level of invertebrates at the U1-site.

Most spiders and beetles (Carabidae, Staphylinidae) inhabiting the soil litter layer of the spruce stand are polyphagous predators. High population densities throughout the year associated with limited mobility make litter decomposing animals favorite prey objects for soil surface dwelling predators. Next to frequency and mobility, body size and palatability of potential prey objects are the most important factors influencing the diet selection of predatory arthropods in the field (Moulder & Reichle 1972). In addition, less sclerotized items without slimy or otherwise distasteful secretions are generally preferred. Taking these facts into account, and drawing on previous work on feeding preferences of zoophagous arthropods, the predation pattern of the most abundant surface dwelling spiders, carabids and staphylinids of the U1-site are as follows (Roth 1991):

The diet of the spiders *D. latifrons* and *Robertus sp.* and the staphylinids *Tachinus* spp. and *T. obtusus* consist at the U1-site predominantly of soil-dwelling Collembola, Sciaridae and Cecidomyiidae. *Coelotes terrestris* and species of the genus *Carabus* and *Abax* are able to overcome larger prey objects. Among these are middle-sized Carabidae, Staphylinidae, Diptera, Araneae and – in the cases of *Carabus* sp. and *Abax* sp. – Lumbricidae. Specimens of *Pterostichus* sp., *Ontholestes tesselatus* and *Philonthus* sp. are attracted by smaller staphylinids, spiders, sciarids, cecidomyiids and springtails. *Notiophilus biguttatus* and *Loricera pilicornis* specialize in capturing Collembola. *Othius punctulatus* feeds on Enchytraeidae, Oribatida, Collembola and Diptera.

Taking these feeding preferences as a basis for the calculation of concentration factors of Pb in spiders, carabid and staphylinid beetles at the U1 site, Pb was not accumulated by any zoophagous arthropod. In most cases, Pb levels in the prey objects exceeded Pb concentrations in predators and the concentration factors were less than unity.

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